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Characteristics and target values of the voltage supplied by the Hydro-Québec medium and low voltage systems

Translated June 5, 2001
French original : February 2001

This document is translated from the French document intitled 'Caractéristiques et cibles de qualité de la tension fournie par les réseaux moyenne et basse tension d’Hydro-Québec ' (Report nr: 30012-01-02).
In case of any difference between the English and French version, the French version shall prevail.

Summary

The purpose of this document is to familiarize customers with the different phenomena affecting voltage quality, to describe these phenomena; and to encourage customers to use this information to adequately protect their equipment and minimise the possible impact of various disturbances.

The characteristics and target values of the voltage presented in this document are general in nature and intended for information purposes only. These figures provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience larger variations of the voltage characteristics and a greater number of events. In no way does this document constitute an obligation or guarantee of any kind whatsoever on the part of Hydro-Quebec.

The document describes, at the connection point to the medium and low-voltage system, the principal characteristics and quality of voltage provided by the Hydro-Quebec distribution system under usual operating conditions. **Unless otherwise noted, the characteristics described in this document apply to medium-voltage as well as low-voltage systems.** They do not apply in cases of force majeure or in other specific situations outlined in the Scope section.

The present document is partly based on practices recommended by national and international electricity supply standards and adapted to the Hydro-Quebec system.

More specifically, this document covers steady state voltage, harmonics, voltage imbalance, flicker, short interruptions, voltage dips, temporary overvoltages, frequency and voltage variations, and transient overvoltages. For certain characteristics, target values are defined with reference to standards and in terms of probability, i.e., they are applicable for a percentage of time in a specific time period. For other characteristics, however, factors such as current knowledge or standardisation, the random or external nature of disturbances, enable us to provide only a general range of values representing current knowledge on the subject.

Furthermore, in order to ensure compatibility between customer equipment and the electricity supplied, this equipment must have adequate immunity levels. Also, disturbances originating from customer equipment or installations must be below authorised emission levels**,** so that their cumulative effect on the system will not create an unacceptable risk of exceeding compatibility levels.

This last aspect, in relation to the control of disturbances produced by the installations of customers connected to the distribution system, falls under Hydro-Québec emission limits requirements. Customers must therefore comply so that the target values presented herein may be reached.

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1. Preamble

The purpose of this document is :

- to familiarize customers with the guidelines generally accepted by the international community or defined by Hydro-Québec for the different phenomena affecting voltage quality;

- to remind customers that supplied electricity is subject to interruption or disturbance;

- to encourage customers to use the information provided to adequately protect their equipment and to organize their use of electricity to minimise the possible impact of the various phenomena as necessary;

- to encourage equipment suppliers to offer the necessary options to ensure the compatibility of their equipment with the normal supply of electricity.

The voltage characteristics defined in this document are general in nature; they should not, therefore, be regarded as complete or sufficient to ensure the correct operation of an installation or a given device.

The customer must therefore consider these phenomena and characteristics in their entirety to ensure the adequate integration of an installation or device in its unique environment, all in accordance with applicable standards and codes.

It is also important to note that the characteristics and target values presented in this document provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience values and a number of events falling outside the bounds described in this document.

In this respect, **Hydro-Québec guarantees neither the maintenance of voltage and frequency at a stable level nor the continuity of the supply and delivery of electricity. In no case shall it be held contractually or extra-contractually liable for damage caused to property resulting from the supply or delivery of electricity or failure to supply or deliver electricity, or resulting from accidental grounding, mechanical failure on its system, any interruption of service, frequency variations or supply voltage variations.** (Bylaw 634, s.102)

Moreover, even when the system is exploited within the limits defined in this document, it is still essential that equipment or processes be designed or immunised in such a way that they are neither disturbed nor damaged by their electrical environment.

This is why **the customer must ensure the protection of property and the safety of persons wherever electricity is supplied or delivered and he is responsible for protecting himself from the consequences of any interruption in the supply or delivery of electricity and for protecting his electrical installation and apparatus from voltage variations and losses, frequency variations and accidental groundings.** (Bylaw 634, s.66)

The measuring methods referred to in these pages are relatively new. As a consequence, the pertinent measuring devices may not be widely available for a few years yet. In the meantime, available measuring devices may be used, with results treated and interpreted respecting the new methods as much as possible.

Context

This document is partly based on practices recommended by national and international standards and adapted to the Hydro-Québec system. Among the standards currently used or being developed on power quality and compatibility between load and power supply, priority was given to standards issued by the International Electrotechnical Commission (IEC) as well as to standard EN50160 [1] of the European Committee for Electrotechnical Standardisation (CENELEC), both among the most advanced standards in the industry.

Furthermore, voltage quality measurements will be taken in the next few years to continue to quantify the various voltage quality indices as applied to the Hydro-Québec distribution system. With these measurements then at hand, the voltage quality disturbance levels given here as a indicative guidelines may be more precisely defined.

Under usual operating conditions, supply voltages are subject to variations for a number of reasons : changes of the load connected to the supply system, disturbances generated by various devices, and faults arising chiefly from external events. Characteristics may vary randomly : over time at a specific supply point, or by location at a given point in time.

Some of the phenomena affecting voltage are especially unpredictable, making it impossible to give definite values for the characteristics in question. So we must define the effect of events on these characteristics in terms of statistics and probabilities, rather than characterizing them by extreme values.

Compatibility of equipment and supply

Electricity supplied at a medium or low voltage connection in perfect conformity to the characteristics set forth in this document cannot guarantee the satisfactory operation of equipment or processes. This guarantee may only be achieved if all equipment or processes are compatible with the power supply.

At the international level, Electromagnetic Compatibility (EMC) is defined as " the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment " [standard IEC 50 (161-01-07)].

There are two conditions necessary for electromagnetic compatibility :

- customer equipment must have immunity levels higher than the compatibility levels specified for any given phenomenon;

- disturbances emanating from customer installations or equipment must be below the system-authorized emission limits so that their cumulative effect does not involve an inadmissible risk of exceeding compatibility levels.

The standards on immunity, such as standard IEC 61000-4-11, “ Voltage dips, short interruptions and voltage variations immunity tests ” cover the characteristics relating to the first aspect.

The desired degree of compatibility between equipment and supply depends of course on the end use of the equipment and the consequences of incompatibility. For example, the momentary interruption of a variable speed drive and the motor it actuates can be acceptable on a ventilation system, but not so for a production line.

For each application, therefore, one must gauge the degree of immunity conferred on a piece of equipment in relation to its source of power. This immunity can be an integral feature of the equipment, but it can also be improved by the use of filters, an uninterruptible power supply, etc.

Concerning the second aspect of compatibility, disturbances generated by the installations of the customers connected to the system, these are covered by Hydro-Québec authorized emission limits, and customers must be in compliance, so that target values presented herein may be reached. To help customers comply, Hydro-Québec will provide them with guides and methods to calculate and validate emission levels before installing their equipment.

Use of electricity

Let us recall that at all times the customer must use electricity according to the available power limit in such a way that he does not disturb Hydro-Québec's system, hinder the supply of electricity to other customers or put Hydro-Québec representatives at risk (Bylaw 634, s.74). The customer is also liable for any damage caused to other customers or to Hydro-Québec for use of electricity not in compliance with Bylaw 634, s.74. (Bylaw 634, s.104)

2. Object

The object of this document is to define and describe the values characterizing the voltage supplied by the Hydro-Québec distribution system — as frequency, magnitude, symmetry of three-phase voltages and waveform — in order to provide customers with better information.

3. Scope

The document describes, at the delivery point from the medium and low voltage system, the main characteristics of the voltage quality provided by the Hydro-Québec distribution system under usual operating conditions.

It does not apply to the following situations :

- exceptional circumstances linked to external influences or events, such as extreme weather conditions, natural disasters, excessive disturbances generated by third parties, *forces majeures*, explosions, accidents or breakage of machinery or equipment, interruptions due to external causes, or if public safety requires it, etc;
- islanded system, operation after a power interruption or under provisional supply conditions during maintenance or construction work or with a view to minimising the extent and duration of a supply cut;
- non-compliance of customer installations or equipment with the relevant codes, standards or Bylaws or with the technical requirements for connection;
- non-compliance of customer installations or equipment with the authorized disturbance emission limits on the Hydro-Québec distribution system;
- non-compliance of power generating plants with the relevant standards or with the requirements for connection of generating stations to Hydro-Québec system;
- autonomous (electrical) systems (e.g. : the Magdalene Islands electrical supply system, the system on the Lower North Shore supplied by the Lake-Robertson generating station, electrical systems supplied with fossil fuel generating units or other types of autonomous generating plants in the Northern communities, etc.);
- neighbouring systems which supply Hydro-Québec customers or substations just as other parts of the Hydro-Québec system that are being supplied by these substations (Hydro-Québec substations and customers supplied by the Alcan power system, part of the Témiscamingue system not connected to the main system but inter-connected with Ontario, the Manicouagan Hydroelectric Co system, the Bryson generating station synchronized with Ontario, etc.)

The characteristics and target values of voltage quality presented in this document are general in nature and intended for information purposes only. These figures provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience values and a number of events falling outside the bounds described in this document. In no way does this document constitute an obligation or guarantee of any kind whatsoever on the part of Hydro-Québec.

At no time can the characteristics and target values presented in these pages can be construed as voiding or amending the provisions of Bylaw 634 respecting the conditions governing the supply of electricity nor serve to interpret the meaning or the scope of that Bylaw whose pertinent provisions are appended hereto. They should also not be interpreted as limits to the disturbances that customers connected to the Hydro-Québec system are allowed to generate (known as emission limits).

For the purpose of this document the following definitions apply :

Autonomous (electrical) system

Any system for the production and distribution of electricity, independent of the main system. (Bylaw 634, s.3)

Compatibility

The ability of a device or system to function satisfactorily and without introducing intolerable disturbances for other devices connected to the electrical supply system. (It is the equivalent of " Electromagnetic Compatibility " defined by the International Electrotechnical Commission).

Connection point

The point where the electrical installation of the premises receiving electricity is connected to the Hydro-Québec system (Bylaw 634, art. 3).

Delivery point

Any point located immediately on the load side of Hydro-Québec metering equipment from which electricity is put at the disposal of the customer. In cases where Hydro-Québec does not install metering equipment, or where it is on the line side of the connection point, the delivery point is the connection point. This is the point where the characteristics and target values of voltage supplied by the distribution system covered in this document are defined.

Continuity index

Represents the mean number of hours of interruption of service per customer in a given zone (province, municipality, substation, line, etc.) in a given period.

Cycle

One period duration of the fundamental frequency wave of the alternating voltage of the supply system. For a frequency of 60 Hz, this duration is 1/60th of a second, that is to say 16.67 milliseconds.

Flicker

The impression of unsteadiness of vision sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. [International Electrotechnical Vocabulary (50-161-08-13)].

Force majeure

Any act of God, labour conflict, act of a public enemy, war, insurrection, riot, fire, storm or flood, explosion, breakage or accident to machinery or equipment, any curtailment, order, regulation or restriction imposed by a military government or legally constituted civilian authorities, or any cause beyond Hydro-Québec's control.

Harmonic voltages

Sinusoidal voltages with a frequency equal to an integer multiple of the fundamental frequency of the system (60 Hz).

Indicative value

For some voltage characteristics, the current state of knowledge or standardisation, or the random or external nature of disturbances, does not enable us to define target values. The indicative values which are then given simply reflect current information on the subject.

Interruption

Power outage lasting more than 1 minute.

Islanded (electrical) system

Electrical system with one or more generating stations and loads which is temporarily disconnected from the main system following a disturbance or a switching operation.

Low voltage

In this document, the term refers to those parts of the distribution system whose nominal voltage between phases is less than 750 V.

Main system

The largest body of Hydro-Québec electrical supply systems linked together.

Measurement period

One continuous week used as a reference period during which statistics are gathered and assessed. Measurements can however be taken for more than one week if necessary.

Medium voltage

In this document, the term refers to those parts of the distribution system whose nominal voltage between phases is 750 V- 34.5 kV (included).

Neutral voltage

The voltage measured between the system neutral conductor and a reference electrode located at least 10 meters from any other ground or metal object.

Neighbouring system

System not belonging to Hydro-Québec, but which can be connected to its main system.

Nominal voltage of low voltage system

R.M.S. voltage between phases used to designate a system. For our purposes, the nominal low voltage system voltages (Vnom) are established as follows :

- 120/240 V, in a single-phase system;
- 347/600 V in a three-phase, wye**,** or grounded neutral system.

Nominal voltage of medium voltage system

R.M.S. voltage between phases used to designate a system. For our purposes, the nominal medium voltage system voltages (Vnom) are established as follows : 4.16 kV, 12.47 kV, 13.2 kV; 13.8 kV; 24.94 kV and 34.5 kV. The usual nominal voltage on the medium voltage system is 24.94 kV.

Rapid voltage changes

Series of sudden variations or cyclic variations of the R.M.S. value of the voltage between two consecutive levels, generally caused by load changes or system switching.

R.M.S. value

Root-mean-square value.

Short interruption

Complete loss of supply voltage on all phases for a period not exceeding 1 minute.

Steady state voltage

R.M.S. value of the voltage evaluated over 10 minutes.

Supply voltage

Voltage supplied at the connection point of the customer.

Supply voltage frequency

Rate of repetition of the fundamental wave of the supply voltage, measured for a specific time interval. The frequency of an alternating voltage of public distribution system is directly related to the number of revolutions of the alternators.

Target value

The limit set for certain voltage characteristics in reference to company objectives or national or international standards. They are often defined in terms of probabilities for a specific percentage and a specific time period. Therefore these limits may occasionally be exceeded.

Temporary overvoltage

Sudden increase in the R.M.S. value of the voltage on one or more phases (more than 110 % of the nominal voltage) for a duration lasting from 8 ms to 1 min.

Transient overvoltage

Very rapid increase in the voltage at high frequency, independent of supply voltage frequency. The overvoltage can take the form of an impulse of negative or positive polarity or of a dampened oscillation. It can be caused by commutation of loads, system switching, or lightning.

Usual operating conditions

Conditions enabling load demand to be met, system switching operations to be carried out and the routine clearing of faults by automatic system protection, in the absence of *force majeure*, exceptional conditions or any temporary operating conditions.

Value defined at 95 %

Applies to a one-week measurement period: a value defined at 95 % means that for 159.6 out of the 168 hours of one week, the measured values are below the target or indicative values defined by its characteristics. For any one-week period, a given characteristic could therefore exceed its corresponding target or indicative value for 8.4 hours.

Voltage dip

Sudden reduction of more than 10 % of nominal voltage on one or more phases lasting from 8 ms to 1 min.

Voltage unbalance

Situation where the three voltages of the three-phase system are not equal in magnitude or are not phase shifted by 120º from one another.

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5. CLASSIFICATION OF THE DISTURBANCES AFFECTING THE ELECTRICAL SUPPLY SYSTEM

The following general classification, provided for information purposes, makes it possible to distinguish the type and the duration of the phenomena under study here, e.g., impact on equipment, recommended methods of measurement and the nature of the values presented.

Phenomena (Typical duration)	**Type**	**Section**	**Possible effects**	**Measurement**	**Target or indicative values**
Long duration or permanent (> 1 min)	• Steady state supply voltage	5.1 and 5.2	Overheating of electronics, motors or transformers	R.M.S. values over 10 minutes	Targets
	• Neutral voltage	5.3	Parasite voltages which may affect agricultural production		Targets
	• Interruption	5.4	Halt of equipment	Duration of interruption	Targets
	• Harmonic voltage	5.5	Overheating of electronics, motors or transformers	R.M.S. values over 10 minutes	Targets
	• Voltage unbalance	5.6		R.M.S. values over 2 hours	Indicatives
	• Flicker	5.7	Impression of visual discomfort	Cubic mean over 2 hours	Targets
Slow transients (> 0,008 s et ≤ 1 min)	• Short interruption	5.8	Halt of equipment	Duration of interruption	Indicatives
	• Voltage dip	5.9	Halt of industrial processes or equipment malfunction	R.M.S. values over one cycle to a few seconds	Indicatives
	• Temporary overvoltage	5.10			Indicatives
	• Frequency variations	5.11			Targets
	• Rapid voltage changes	5.12			Indicatives
Rapid transients (≤ 0,008 s)	• Transient overvoltage	5.13 and 5.14	Halt of industrial processes, insulation failure	Crest value and waveform See reference [2]	Indicatives

5.1 STEADY STATE VOLTAGE - LOW VOLTAGE

5.1.1 Description

In compliance with Article 19 of Bylaw 634 on the conditions concerning the supply of electricity, low voltage system nominal voltages are established as follows :

- 120/240 V, in a single-phase system;
- 347/600 V in a three-phase, wye**,** or grounded neutral system.

5.1.2 Causes of variations

In an electrical supply system, the steady state voltage magnitude depends on system design characteristics, load changes and other changes to which the system is subjected. It is common practice to correct steady state voltage at various points on the system, for example, using automatic tap changers at the transformer substations and on some distribution feeders.

5.1.3 Method of evaluation

Steady state voltage variations are evaluated by taking the quadratic mean of the R.M.S. value variations in relation to nominal voltage over 10-minute time integration intervals. The target values presented on the following page must be compared, for the applicable case, with the value corresponding to 95 % or 99.9 % of the results obtained over a one-week measurement period, excluding interruptions. Measurement methods are described in reference [2].

5.1.4 Target values of steady state supply voltages

For every one-week period, under usual operating conditions, excluding interruptions, 95 % of R.M.S. values of variations evaluated over 10 minutes will vary between -11.7 % and +5.8 % from nominal voltage. The fluctuation voltage supplied falls within the range recommended by the Canadian Standards Association (standard CAN3-C235-83), marginal conditions included, as follows :

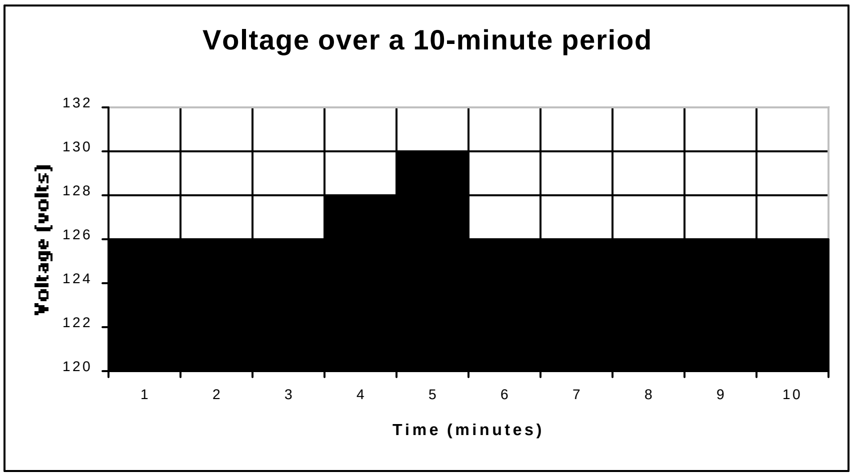
- for nominal voltage 120/240 V, 106/212 V - 127/254 V;
- for nominal voltage 347/600 V, 306/530 V - 367/636 V;

Finally, 99.9 % of R.M.S. values of variations evaluated over 10 minutes fall within -15 % to +10 % of nominal voltage, established as follows:

- for nominal voltage 120/240 V: 102/204 V - 132/264 V;
- for nominal voltage 347/600 V: 295/510 V - 382/660 V;

Example

For the voltage profile given below, the R.M.S. value integral calculated over 10 minutes yields a variance of + 5,6 %, i.e., a voltage R.M.S. value of 126.7 V, even considering fluctuations of up to 8.3 % for 1 minute (130 V).



5.2 STEADY STATE VOLTAGE – MEDIUM VOLTAGE

5.2.1 Description

In compliance with Hydro-Québec Bylaw 634, medium voltage system nominal voltages are established as follows :

- 2,4/4,16 kV ;
- 7,2/12,47 kV ;
- 7,6/13,2 kV ;
- 8,0/13,8 kV ;
- 14,4/24,94 kV ;
- 20,0/34,5 kV .

5.2.2 Causes of Variations

In an electrical supply system, the steady state voltage magnitude depends on system design characteristics, load changes and other changes to which the system is subjected. It is common practice to correct steady state voltage at various points on the system, for example, using automatic tap changers at the transformer substations and on some distribution feeders.

5.2.3 Method of Evaluation

Steady state voltage variations are evaluated by taking the quadratic mean of the R.M.S. value variations in relation to nominal voltage over 10-minute time integration intervals. The target values presented on the following page must be compared, on a case-by-case basis, with the value corresponding to 95 % or 99 % of the results obtained over a one-week measurement period, excluding interruptions. Measurement methods are described in reference [2].

5.2.4 Target values of steady state supply voltages

For every one-week period, under usual operating conditions, excluding interruptions, 95 % of R.M.S. values of variations evaluated over 10 minutes will vary by plus or minus 6 % from nominal voltage. Finally, 99.9 % of R.M.S. values of variations evaluated over 10 minutes fall within plus or minus 10 % of nominal voltage.

For example, for nominal voltage 14.4/24.94 kV, for each one-week period :

- 95 % of R.M.S. values of variations evaluated over 10 minutes will fall between 13.58/23.52 kV and 15.26/26.43 kV
- 99 % of R.M.S. values of variations evaluated over 10 minutes will fall between 13.09/22.67 kV and 15.84/27.43 kV

5.3 NEUTRAL VOLTAGE (GROUND-NEUTRALVOLTAGE)

5.3.1 Description

This is the voltage existing between a grounded electrode linked to the neutral and a reference electrode located 10 meters from the grounded electrode and any other metal object which could alter the soil gradient potential. In the agricultural industry, this voltage between the neutral and the ground is sometimes called « parasitic voltage » as it may upset some animals and have consequences on farm production.

5.3.2 Causes of variations

In an electrical supply system, the magnitude of grounded neutral voltage depends on the one hand on homopolar current magnitude stemming from load distribution among the three system phases and on the other from the distribution of the current between the ground cable and the soil. This distribution is a function of grounding impedances, the nature of the soil, its humidity rate, etc.

5.3.3 Method of evaluation

Neutral voltage is evaluated by taking the quadratic mean of R.M.S. values sampled over a 10-minute period just like steady state voltage. Measurement methods are described in reference [2].

5.3.4 Neutral voltage target value (ground-neutral voltage)

For each one-week period, under usual operating conditions, 95 % of R.M.S. values evaluated over 10 minutes will not exceed 10 volts[1].

[1] Ground-neutral voltage may temporarily reach higher values (a few kilovolts in the worst case scenario), in a disrupted mode (i.e., ground short-circuits, single phase manoeuvres…)

5.4 INTERRUPTIONS (DURATION ^{3} 1 MINUTE)

5.4.1 Description

Hydro-Québec delivers and provides electricity subject to interruptions which may result from emergency situations, accidents, equipment breakage or the activation of system protection equipment. (Bylaw 634, a.94)

Hydro-Québec may interrupt, at any time, the provision or delivery of electricity for maintenance, repairs, system modification or management, or reasons of public utility or public safety. (Bylaw 634, a.95)

5.4.2 Causes

Accidental interruptions may stem from internal or external causes. In a large number of cases, they originate in external causes or events beyond the control of Hydro-Québec. Given the considerable differences in system architectures and the unpredictable effects of third-party actions or of inclement weather, it is difficult to establish annual frequencies and typical mean durations for these kinds of interruptions.

5.4.3 Method of evaluation

The continuity index (C.I.), which quantifies interruptions is a cumulative value weighted over one year; it may result from several interruptions or a single interruption of longer duration. It is calculated as follows :

$$\text{C.I. (hours)} = \frac{\text{Sum of customer-hours interrupted}}{\text{Sum of all customers}}$$

The continuity index may therefore be calculated for all customers in the province, for a given territory, for a particular substation or by distribution line. This index is used by the vast majority of electricity utilities in North America to quantify their system's quality of service continuity. It is expressed in hours.

5.4.4 C.I. target values

The C.I. forms part of the firm's objectives and the provincial target values form part of the Hydro-Québec strategic plan, published every two years. As an example, for 1999 and 2000, target and real values were :

Provincial distribution C.I. target and actual values (weighted hours)		
Provincial C.I.	1999	2000
Target value	2.2	2.1
Real value	2.16	1.97

All the same, C.I. information varies with the locality of each customer. A service continuity case history for each customer's district may be obtained from Hydro-Québec as needed.

Unusually long interruptions

When circumstances beyond the control of Hydro-Québec lead to an interruption lasting more than 24 hours (or 12 hours in winter), the firm activates an emergency plan to restore service and minimize the impact of the interruption.

5.5 HARMONIC VOLTAGES

5.5.1 Description

Harmonics are sinusoidal voltages or currents whose frequencies are integer multiple of the fundamental frequency (60 Hz). The present definition covers long duration harmonics, excluding isolated transient phenomena.

5.5.2 Causes

Harmonics are caused by devices whose voltage/current characteristic is not linear, e.g., electronic power converters for motor drives, rectifiers used for electrolysis, arc furnaces, etc.

5.5.3 Method of evaluation

Harmonic voltages are individually measured by magnitude (Un), generally expressed as a percentage magnitude of the fundamental voltage (U1)[2]. The individual harmonics factor (Dn) and the total harmonic factor (D) are calculated as follows :

Individual harmonic factor :

$$D_n = \frac{U_n}{U_1} \bullet 100\%$$

(*n* : harmonic order)

Total harmonic factor :

$$D = \sqrt{\sum_{n=2}^{N} \left(\frac{U_n}{U_1} \right)^2} \bullet 100\%$$

Unless specific conditions apply, *n* is usually equal to 50.

Individual harmonic factors (Dn) and the total harmonic factor (D) correspond to the harmonic voltage R.M.S. value measured over 10-minute integration time intervals. Harmonic voltage levels are evaluated excluding periods with fast transients, voltage dips, temporary overvoltages, short interruptions and interruptions, or periods when three-phase voltage falls below 50 % of nominal voltage. The measurement method is described in reference [2].

[2] Note : Harmonic factors can also be expressed relative to a fixed reference voltage such as nominal voltage, rather than relative to the fundamental voltage. Evaluation of harmonic factors relative to a fixed reference makes it possible to find the absolute levels of harmonics even if the fundamental component fluctuates.

5.5.4 Target values

In the case of harmonic voltages, the harmonic factors (D) equal 8 % and the individual harmonic factors should be lower than the values set out below, 95 % of the time over a one-week measurement period under usual operating conditions.

INDIVIDUAL HARMONIC TARGET VALUES
FOR MEDIUM AND LOW VOLTAGE SYSTEMS [3]

Odd Harmonics		Even Harmonics	
Harmonic Order	Harmonic Voltage %	Harmonic Order N	Harmonic Voltage %
3	6	2	2.0
5	6	4	1.5
7	5	6	0.75
9	3.5	8	0.6
11	3.5	10	0.6
13	3	12 – 24	0.5
15	2		
17	2		
19 - 25[4]	1.5		

[3] Values for harmonics may reach values higher than those indicated in this table following uncontrollable events such as geomagnetic storms, etc.

[4] Values corresponding to harmonics of a higher order than 25 are very unpredictable by virtue of resonance effects. The indicative values presented here may be replaced by more precise one a few years from now following a measurement campaign conducted on the distribution system.

5.6 VOLTAGE UNBALANCE

5.6.1 Description

This index characterises the magnitude and phase angle asymmetries of three-phase voltages in steady state operation. The voltage unbalance factor is defined using the theory of symmetrical components, as the ratio between the voltage negative sequence component and positive sequence component.

5.6.2 Causes

Voltage unbalances, which apply to three-phase voltages, have two main causes, i.e., asymmetries of line impedance and load unbalances.

5.6.3 Method of evaluation

The voltage unbalance factor is evaluated using the R.M.S. value of the positive and negative sequence voltage components over two-hour time integration intervals under usual operating conditions. Periods during which the voltage of the three phases is lower than 50 % of nominal voltage are excluded from this evaluation. The measurement method is described in reference [2].

5.6.4 Indicative values

Voltage unbalance factors under usual operating conditions 95 % of the time over a one-week measurement period are generally less than 2 %. However, where line or load characteristics make it impossible to allocate the load among phases in an optimal fashion (three-phase lines which include long two-phase or single-phase junctions), some voltage unbalances may reach 3 % at three-phase delivery points, under usual operating conditions.

Notes These values do not cover voltage unbalances caused by uncontrollable events such as geomagnetic storms, etc.

Higher values may be recorded over a limited period of time (50 % of voltage unbalance during a short-circuit, for example), but these short-duration high unbalance levels do not produce a significant heating effect on equipment.

5.7 FLICKER

5.7.1 Description

Flicker translates the visual discomfort caused by repetitive changes of brightness in lighting. At certain frequencies, the eye can perceive the effect of very small voltage fluctuations on lighting. Most equipment, however, is not disturbed by this phenomenon.

5.7.2 Causes

Flicker derives from voltage repetitive variations caused by certain industrial loads such as welding machines, rolling mills, large motors with variable loads, arc furnaces, etc.

5.7.3 Method of evaluation

The index used to evaluate long-term flicker severity is the Plt, evaluated over two-hour time integration intervals. Flicker is measured with a flickermeter according to standard IEC 61000-4-15:1997 [5] whose weighting factors must be corrected for incandescent lamps at 120 V. The measurement method is described in reference [2].

5.7.4 Target value

Under usual operating conditions, the level of flicker caused by supply voltage variations is generally lower than Plt = 1.0 (index for long-term flicker level), 95 % of he time over a one-week measurement period.

5.8 SHORT INTERRUPTIONS *(duration < 1 min)*

5.8.1 Description

Short interruptions correspond to a temporary loss of supply voltage on all phases lasting less than 1 minute.

5.8.2 Causes

Most of the time, short interruptions are caused by the action of devices designed to protect the system from short-circuits. On medium voltage lines, it is current practice to automatically reclose circuit breakers to restore power supply as soon as possible on a line disturbed by a fugitive fault. So, instead of an interruption, customers supplied by the disturbed line have just a short interruption lasting from 2 to 60 seconds, in the absence of co-ordination constraints on protections. Of course any automatic reclosing will affect all the medium and low voltage customers connected to the downstream network

It must be stressed that automatic reclosing is used to ensure better continuity of service, by making it possible to avoid interruptions from fugitive faults. On the other hand, if the fault is permanent, the number of voltage dips for customers supplied by other lines increases a little.

5.8.3 Method of evaluation

In practice, voltage dips of more than 90 % may be viewed as short interruptions, since less than 10 % of effective voltage supplying equipment then remains. The measurement method is described in reference [2].

5.8.4 Indicative values

Under usual operating conditions, there may be dozens — maybe as many as a hundred — short interruptions in the course of a year, depending on the length of the system[5]. The duration of about 50 % of short interruptions is below three seconds, and the duration of about 90 % of them does not exceed 20 seconds.

[5] Appendix A provides the maximum occurrences of short interruptions and voltage dips observed at 17 Hydro-Québec system medium voltage sites.

5.9 VOLTAGE DIPS

5.9.1 Description

Voltage dips are sudden reductions of more than 10 % of nominal voltage, lasting between 8 milliseconds and a minute.

5.9.2 Causes

Voltage dips are generally caused by a large current inrush generated by short-circuits on the system or on customer installations. They are unpredictable, largely random events. The annual frequency varies greatly with the type of supply system and point of observation, and their distribution over the year can be very irregular[6].

5.9.3 Method of evaluation

The magnitude of voltage dips is measured by the percentage of voltage reduction, and their duration by the time during which the R.M.S. voltage of one of the phases — evaluated over every consecutive cycle of the 60 Hz waveform — falls below the threshold of 90 % of nominal voltage[7]. Measurement is continued until the voltage returns above this threshold. For a single event, the magnitude of voltage dips measured between phase-to-neutral differs from the phase-to-phase value. Values measured between phase-to-phase are generally more representative of the effect of voltage dips on industrial loads. The measurement method is described in reference [2].

5.9.4 Indicative values

The annual number of voltage dips is unpredictable and varies greatly from place to place. In urban areas, where the distribution system is largely underground, there may be an average of 1-4 voltage dips a month. In rural areas, on the other hand, there will be more. Voltage dips generally last less than 1 second with a magnitude of less than 60 %.

[6] Appendix A provides, for reference purposes, the maximum occurrences of short interruptions and voltage dips observed at nine Hydro-Québec network low voltage sites.

[7] If the magnitude of the steady state voltage is situated between 85 % and 90 % of nominal voltage, the detection threshold used will be 85 % instead of 90 % (for instance, 102 V for a nominal voltage of 120 V).

5.10 TEMPORARY OVERVOLTAGES

5.10.1 Description

Temporary overvoltages are sudden rises of the voltage R.M.S. value of more than 110 % of nominal voltage. Temporary overvoltages may last between 8 milliseconds and one minute.

5.10.2 Causes

Temporary overvoltages may be caused by short-circuits, load rejections or resonance and ferro-resonance phenomena. Generally, they result from overvoltages induced on healthy phases, during phase-to-ground faults for instance.

5.10.3 Method of evaluation

We have a temporary overvoltage when voltage magnitude and the time during which the R.M.S. voltage of one of the phases —assessed over every consecutive cycle of 60 Hz — exceeds the 110 % nominal voltage threshold. Measurement is continued till voltage of the three phases falls below this threshold once again. The measurement method is described in reference [2].

5.10.4 Indicative values

The importance of overvoltages which are caused by single phase-to-ground short-circuits varies with fault location, system impedance and the effectiveness of neutral grounding, as follows :

- in the case of systems whose neutral is effectively grounded, phase-to-ground overvoltages on healthy phases are generally lower than 140 % and typically last a few cycles to a few seconds, depending on the speed with which protection devices eliminate the fault;

- in the case of systems whose neutral is isolated or ungrounded, phase-to-ground overvoltages on the phases can reach 180 %[8] , and systems of this type are designed according to such constraints.

[8] Note: Higher overvoltages can be generated by an arcing ground fault when the neutral is grounded through a capacitance, but such situation would be abnormal.

5.11 FREQUENCY VARIATIONS

5.11.1 Description

The nominal frequency of the alternating voltage supplied by the Hydro-Québec system is 60 Hz. This value is determined by the speed of the alternators at generating stations.

5.11.2 Causes of variations

Maintaining system frequency depends on the balance between the load and the power produced by the generating stations. As this balance changes over time, we see small frequency variations whose magnitude and duration depend on load characteristics and on the response of generators. Additionally, the system may be subjected to greater variations from short-circuits, or load or generation changes causing temporary frequency variations whose magnitude and duration depend on the severity of the disturbance [9].

5.11.3 Method of evaluation

Evaluated using the mean value of the system fundamental frequency, assessed over samples of 12 consecutive cycles. The measurement method is described in reference [2].

5.11.4 Target value

The following value is based on standard CENELEC-EN50160 [1]. Under usual operating conditions, the main system frequency is maintained in a range less than plus or minus 1 % or 0.6 Hz (that is to say between 59.4 Hz and 60.6 Hz), for at least 99 % of time over a one-week measurement period.

[9] Appendix B provides maximum frequency variation statistics monitored during disturbances occurring on the Hydro-Québec main distribution system between January 1991 and December 1998. As we see, frequency variations under normal operating conditions fall well within target values.

Remark : Higher frequency variations, for instance, plus or minus 4 Hz around the 60 Hz fundamental frequency (56 Hz with 64 Hz), can occur temporarily on parts of the system islanded following major disturbances or outages.

5.12 RAPID VOLTAGE CHANGES

5.12.1 Description

Rapid voltage changes are sudden but relatively weak voltage variations over the range of values defined for steady state voltage.

Occasional rapid voltage changes do not necessarily have much effect on flicker, but they can disturb some equipment, so their amplitude must therefore be limited.

5.12.2 Causes

Most of the time, they result from load changes on customer installations or from switching operations on the supply system. They can be occasional or repetitive.

5.12.3 Method of evaluation

Establishing the maximum difference of the R.M.S. voltage between two intervals, selected from three 3-second consecutive intervals. The R.M.S. voltage is evaluated over three-second time integration intervals. The measurement method is described in reference [2].

5.12.4 Indicative values

Under usual operating conditions, the magnitude of rapid voltage changes does not generally exceed 8 % of nominal voltage. In some specific environments (an industrial park, for example), it may reach 10 % of nominal voltage.

5.13 TRANSIENT OVERVOLTAGES - LOW VOLTAGE

5.13.1 Description

These are disturbances of very short duration, lasting typically less than one half-cycle, i.e. a few microseconds (µs) to several milliseconds (ms). Transient overvoltages can be impulses or oscillations and they can damage equipment insulation or electronic components.

5.13.2 Causes

Overvoltages may be caused by :

- switching of system lines and equipment, in particular, the switching-in of capacitor banks resulting in a damped oscillation that superimposes onto the fundamental wave, whose oscillation frequency generally lies between 100 Hz and 9 kHz, with a peak duration less than ½ cycle;

- Switching of inductive loads producing fast transients whose rise time typically varies between 0.5 µs to 5 µs.

- lightning, which, outdoors, can generate a unidirectional impulse with — in the most rapid cases — a rise time in the order of one microsecond and a crest value reaching 10kV, even 20 kV;

- lightning, which, indoors, can generate a dampened oscillating wave, with a frequency of 5 kHz to 500 kHz, a rise time less than one microsecond and a crest value typically limited to 6 kV.

5.13.3 Method of evaluation

Measuring the voltage waveform and its instantaneous crest value with a device of sufficiently large bandwidth compared to the frequency of the phenomena considered. The measurement method is described in reference [2].

5.13.4 Indicative values

Transient overvoltage crest values on open circuits (worst case) are generally limited to 6kV inside buildings and between 10kV and 20kV outside. These values are established depending on the insulation voltage of low voltage installations. In practice, these values are considerably reduced by the presence of connected equipment with its protective devices.

In the case of the switching in of shunt capacitor banks, a frequent operation on the network, the magnitude of transient overvoltages is typically lower than twice the system crest line-to-ground voltage. This value can be higher in the case of wave reflections or resonance between customer equipment and the supply system.

5.14 TRANSIENT OVERVOLTAGES - MEDIUM VOLTAGE

5.14.1 Description

These are disturbances of very short duration, lasting typically less than one half-cycle, i.e. a few microseconds (µs) to several milliseconds (ms). Transient overvoltages can be impulses or oscillations and they can damage equipment insulation or electronic components.

5.14.2 Causes

Overvoltages may be caused by :

- switching of system lines and equipment, in particular, the switching-in of capacitor banks resulting in a damped oscillation that superimposes onto the fundamental wave, whose oscillation frequency generally lies between 100 Hz and 9 kHz, with a peak duration less than ½ cycle;

- lightning, generally resulting in the appearance of an impulse; in the fastest cases, a rise time of about one microsecond. A lot of attention is paid to transient overvoltages when it comes to coordinating the insulation of equipment connected to medium voltage systems, and they are covered by various standards, including standards CSA CAN3-C308 [4], and those of the IEC series 71 [6].

5.14.3 Method of evaluation

Measuring the voltage waveform and its instantaneous crest value with a device of sufficiently large bandwidth compared to the frequency of the phenomena considered. The measurement method is described in reference [2].

5.14.4 Indicative values

In the case of the switching in of shunt capacitor banks, a frequent operation on the network, the magnitude of transient overvoltages is typically lower than twice the system crest line-to-ground voltage. This value can be higher in the case of wave reflections or resonance between customer equipment and the supply system.

6. References

This document is based on the work of the inter-division internal working group on supply voltage characteristics and on the following references :

[1] Voltage characteristics of electricity supplied by public distribution systems, Standard CENELEC EN50160:1994.

[2] Measurements methods of the characteristics and target values of the voltage quality supplied by Hydro-Québec system. IREQ, December 2000

[3] Preferred voltage levels for AC systems 0 to 50000V, Standard CSA CAN3-C235-83.

[4] Testing and measurement techniques –Section 15: Flickermeter – Functional design specifications. IEC 61000-4-15:1997 Standard

[5] The Principle and Practice of Insulation Coordination - Electric Power Systems and Equipment. CSA CAN3-C308-M85 Standard.

[6] Insulation Coordination, Parts I and 2. Standards IEC 71-1 and 71-2.

Note : Some works are cited for information purposes only and are therefore not necessarily applicable to Hydro-Québec.

APPENDIX A

STATISTICS ON VOLTAGE DIPS AND SHORT INTERRUPTIONS ON THE LOW AND MEDIUM VOLTAGE SYSTEMS

The following data are taken from a measuring campaign conducted in an industrial setting during 1995-1996.

The following two tables positions the phenomena on the grid of voltage dips normally generated on the supply system. The first table identifies events generating voltage dips typically attributable to customers.

Customer-generated dips

<table>
<tr><th>MAGNITUDE/DUR-></th><th><0,1s</th><th>0,1s<t<0.5 s</th><th>0.5s<t<1 s</th><th>1s<t<3 s</th><th>3s<t<20s</th><th>20s<t<60 s</th><th>>60s</th></tr>
<tr><td>10 % … < 15 %</td><td colspan="2" rowspan="2">Load variation</td><td colspan="3" rowspan="2">Start of load motor</td><td></td><td></td></tr>
<tr><td>15 % … < 30 %</td><td></td><td rowspan="4">Customer fault</td></tr>
<tr><td>30 % … < 60 %</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>60 % … < 100 %</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>100 %</td><td colspan="5">Untimely customer fault</td><td></td></tr>
</table>

The second table positions the voltage dips typically generated by events attributable to the Hydro-Québec system. These events are chiefly causes by the system protection circuit. This is adjusted to provide the best quality service for all customers. For example, on the aerial network, Hydro-Québec uses reactivation which makes it possible to restore service over temporary faults (animals, tree branches, etc.) in a matter of seconds. The number of temporary faults is three times higher than permanent faults.

Dips originating in the system

<table>
<tr><th>MAGNITUDE/ DUR-></th><th><0,1s</th><th>0,1s<t<0,5 s</th><th>0,5s<t<1 s</th><th>1s<t<3s</th><th>3s<t<20s</th><th>20s<t<60 s</th><th>>60s</th></tr>
<tr><td>10 % … < 15 %</td><td colspan="2" rowspan="5">Instantaneous protection element</td><td colspan="4">Distant short-circuit or another customer's load</td><td>Drop in voltage</td></tr>
<tr><td>15 % … < 30 %</td><td colspan="2">Time delay protection</td><td></td><td></td><td></td></tr>
<tr><td>30 % … < 60 %</td><td rowspan="3"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>60 % … < 100 %</td><td></td><td></td><td></td><td></td></tr>
<tr><td>100 %</td><td colspan="3">Reclosure on the same segment</td><td>Loss of power</td></tr>
</table>

Measurements were taken in the neutral phase during the measurement campaign.

When equipment is connected phase-to-phase, the observed magnitude of voltage dips is less. According to study statistics, close to 60 % of voltage dips are single-phase.

The following table provides the results of voltage dip measurements taken on the Hydro-Québec system at 17 sites in Québec. It represents the mean value of the annual number of voltage dips based on the measurements undertaken.

Mean occurrences of 17 sites (on an annual basis).

Dips originating on the system

MAGNITUDE/ DUR>	<0,1s	0,1s<t<0,5 s	0,5s<t<1 s	1s<t<3 s	3s<t<20s	20s<t<60 s	>60s	Total
10 % … < 15 %	174.3	23.0	6.9	3.2	2.8	1.2	1.8	213.2
15 % … < 30 %	32.1	10.7	3.5	0.0	0.0	0.4	0.8	47.5
30 % … < 60 %	11.8	3.9	1.5	1.1	0.0	0.0	0.3	18.6
60 % … < 100 %	2.7	0.0	0.2	0.0	0.0	0.0	0.4	3.3
100 %	0.6	0.0	0.0	2.7	4.2	0.2	4.6	12.3
Total								295.0

With respect to voltage dips results originating with the usual operations of the customer, those are strongly dependent on the nature of the customer's facilities. Concerning this particular measuring campaign, the apparatus was installed with highly disruptive customers (Arc furnaces, starting of high power motors, etc.). Results are thus not representative of typical voltage dips. And that is why they have not been included in this document.

APPENDIX B

STATISTICS ON FREQUENCY VARIATIONS

The following statistics are based on measurement of the maximum values of frequency variations recorded during disturbances on the Hydro-Québec main system between January 1991 and December 1998. The average occurrence is derived on an annual basis from statistics on events occurring in that period.

FREQUENCY VARIATIONS (DF)	SYSTEM CONDITION	AVERAGE OCCURRENCE	TYPICAL DURATION
+ 0.5 Hz to + 1 Hz	Rare disturbed conditions	Once a year	-
+ 0.20 Hz to + 0.5 Hz	Frequent disturbed conditions	24 times a year	Typically less than 10 s, but can occasionally last several minutes.
± 0.20 Hz	**Usual conditions without disturbances**		**Steady State**
- 0.20 Hz to - 0.5 Hz	Frequent disturbed conditions	49 times a year	Typically less than 10 s, but can occasionally last several minutes
- 0.5 Hz to - 1 Hz	Frequent disturbed conditions	20 times a year	
-1 Hz to - 1.5 Hz	Rare disturbed conditions	Less than once a year	-

Remark : Higher frequency variations, for instance, plus or minus 4 Hz around the fundamental frequency of 60 Hz (56 Hz with 64 Hz), can occur temporarily on parts of the system islanded following major disturbances or outages.

APPENDIX C

EXTRACTS FROM BYLAW NUMBER 634 RESPECTING THE CONDITIONS GOVERNING THE SUPPLY OF ELECTRICITY

Act respecting Hydro-Québec, (R.S.Q., c.H-5, s.22.01)

Reference to some provisions of Bylaw 634 on the conditions governing the supply of electricity does not render inapplicable the whole of the provisions of the aforesaid Bylaw.

64. The customer's electrical installation must correspond to information supplied by the customer to Hydro-Québec pursuant to Section 76 and must allow connection at the voltage supplied by Hydro-Québec.
The installation must be approved or authorized by an authority having jurisdiction in this realm pursuant to any applicable legislative or regulatory provision and must be built, connected, protected, utilized and kept up in such a way that it does not disturb the system, jeopardize the quality of the supply of electricity to the installations of the other customers or put Hydro-Québec's representative at risk.

66. The customer must ensure the protection of property and the safety of persons wherever electricity is supplied or delivered and he is responsible for protecting himself from the consequences of any interruption in the supply or delivery of electricity and for protecting his electrical installation and apparatus from voltage variations and losses, frequency variations and accidental groundings.

67. The type, characteristics and adjustment of the customer's protective equipment must allow for coordination of the customer's protection with that of Hydro-Québec.

68. When electricity is supplied at medium or high voltage by several power lines, the customer must use it through the lines Hydro-Québec indicates to him.
Where one of designated lines fails or requires an outage, the customer must, with Hydro-Québec's authorization or at its request, use the electricity through another line indicated by Hydro-Québec, solely for the duration of work, unless Hydro-Québec indicates a longer period of use to him.

69. The customer may not use electrical generating equipment in parallel to Hydro-Québec's system, unless he obtains Hydro-Québec's written authorization to do so.

70. When the customer installs an emergency generator set, the latter must be equipped with a manual or automatic switching device authorized by Hydro-Québec.

71. The customer must immediately inform Hydro-Québec of any electrical or mechanical defect in his electric installation likely to disturb Hydro-Québec's system, jeopardize the supply of electricity to other customers or put property or persons at risk.

72. When electricity is supplied at medium or high voltage, Hydro-Québec, in order to manage its system, must be able to communicate at all times with authorized persons pursuant to the Master Electricians Act (R.S.Q., chapter M-3), designated by the customer.

The customer must immediately inform Hydro-Québec of the replacement of the aforesaid persons.

74. The customer must use electricity according to the available power limit in such a way that he does not disturb Hydro-Québec's system, hinder the supply of electricity to other customers or put Hydro-Québec's representative at risk

76. The customer provides Hydro-Québec with information respecting the use to which electricity is put and the characteristics of his electrical installations, as required for the management or safety of the system. He then must notify Hydro-Québec immediately of any change in the information supplied.

94. Hydro-Québec delivers and supplies electricity subject to interruptions which may arise from an emergency, an accident, equipment failure or the activating of protective equipment within the system.

95. Hydro-Québec may, at any time, interrupt the supply or delivery of electricity for the purpose of upkeep, repairs, modification or management of the system, or for reasons of public utility or safety.

102. Hydro-Québec guarantees neither the maintenance of voltage and frequency at a stable level nor the continuity of the supply and delivery of electricity. In no case shall it be held contractually or extra-contractually liable for damage caused to property resulting from the supply or delivery of electricity or failure to supply or deliver electricity, or resulting from accidental grounding, mechanical failure on its system, any interruption of service covered by Division V of chapter VI, frequency variations or supply voltage variations.

Hydro-Québec shall not be held liable for damage resulting from a steady state supply voltage not exceeding the following limits:

(1) if the electricity is supplied at low or medium voltage: according to the standard mentioned in Section 18;

(2) if the electricity is supplied at high voltage: a difference of up to 10% above or below the nominal supply voltage.

Hydro-Québec shall not be held liable for damage resulting from events of force majeure, even when such events or force majeure cause supply voltage variations exceeding the limits mentioned in the second paragraph.

104. Any contract and any agreement concluded under this Bylaw, any installation effected by Hydro-Québec and any connection between the system and the customer's electrical installation, any authorization given by Hydro-Québec, any inspection or verification effected by it, and the supply and delivery of electricity by it do not constitute and must be interpreted as constituting an evaluation or a guarantee by Hydro-Québec of the functional value, efficiency or safety of the customer's installations, including his electrical installation and protective devices, nor of their compliance with any applicable legislative or regulatory provision.

When the customer does not use electricity according to Section 74, he is liable for any damage caused to other customers or to Hydro-Québec.